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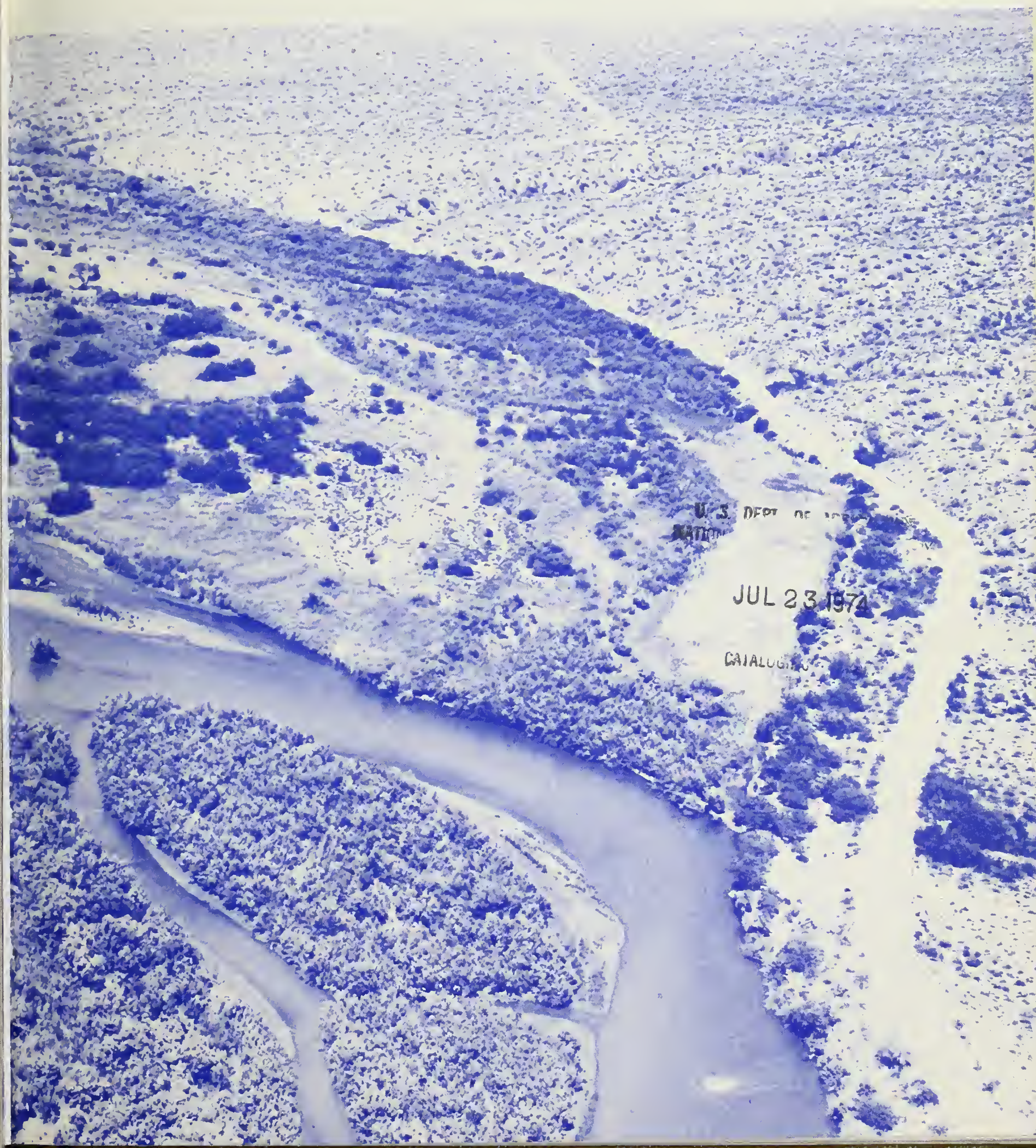
MANAGEMENT OF PHREATOPHYTE AND RIPARIAN VEGETATION FOR MAXIMUM MULTIPLE USE VALUES

by Jerome S. Horton and C. J. Campbell



ABSTRACT

Summarizes the status of our knowledge about environmental relations of vegetation along water courses in the southwestern United States, and impacts of vegetation management to reduce evapotranspiration on other resource values. Reviews the literature on measurement and evaluation of water losses from moist-site vegetation, ecological relationships, other resource uses of phreatophyte and riparian areas, and control methods. Suggests approaches to management of moist-site areas by zones based primarily on water table depth, elevation, and tree species.

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Management of Phreatophyte and Riparian Vegetation for Maximum Multiple Use Values

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Contents

Management of Phreatophyte and Riparian Vegetation for Maximum Multiple Use Values

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Human impact upon the vegetation along the streams and rivers of the southwestern United States began with the development of relatively stable Indian cultures many centuries ago. This impact was intensified with the exploration and development of the Spanish and Mexican cultures. However, major changes came with the arrival of the Anglo-American pioneers who began to develop extensive civilizations along the river flood plains involving the removal of trees and clearing of land for agriculture and houses. Diversion of water from the streams and rivers for irrigation created water shortages in a comparatively short time. Large irrigation projects altered the water regime along the rivers and, consequently, the phreatophyte vegetation occupying flood-plain zones. In contrast, man changed the vegetation along mountain streams only in meadows and the larger valleys, or where water was impounded by dams and diverted away from the normal stream channel.

Soon after major irrigation systems were developed, the problem of water shortage again became paramount in the minds of engineers and planners. Investigations into the problem of water losses were started in southern California during the dry years of the late 1920's when the California Division of Water Resources (1930, 1933), in cooperation with several U.S. Government agencies, started research to determine water losses from moist-site vegetation. This work included lysimeter or tank studies, riparian reach studies, and surveys of water-losing areas as well as studies of irrigation losses. This same extensive cooperative approach was used in surveys carried on later in New Mexico on the Rio Grande (National Resources Committee 1938), and on the Pecos River (National Resources Planning Board 1942). These early studies furnished much of the data used by Blaney and Criddle (1962) in developing their method of predicting consumptive use for river basins and flood plains.

The U.S. Geological Survey was one of the first agencies to become intensely interested in research in water losses from river flood plains of the Southwest (Robinson 1958). It had been concerned with this problem since Meinzer (1923) had coined the word "phreatophyte" from the Greek meaning "well plant," and wrote the first major article dealing with phreatophytes in the Southwest. USGS work, which consisted of many detailed studies including tanks, reach studies, surveys, and analysis of water losses, has continued to the present. The U.S. Bureau of Reclamation has also carried on or sponsored extensive research in determination of water losses from phreatophytes to aid in development of their action programs.

In Arizona, New Mexico, and Texas, the water losses along the rivers became of particular interest as the introduced saltcedar (Tamarix chinensis Lour.[2]) spread vigorously in the reservoir deltas and along the major rivers. This spread was viewed with considerable alarm, and efforts were made to develop methods of control. The research approach was twofold: (1) to initiate studies to evaluate water losses to determine if clearing programs could be justified, and (2) to develop means of controlling saltcedar. In many cases, this research was done

[2] *The authors agree with Baum (1967) in rejecting the use of the name* Tamarix pentandra *(Pall.) for saltcedar.*

Phreatophyte vegetation growing along the Salt River near Granite Reef Dam, Arizona:

1. Tamarisk and associated seepwillow on the islands and along the river in the foreground.
2. Tamarisk and Bermudagrass, in the old river channel parallel to the road.
3. Cattail (Typha spp.).
4. Mesquite.
5. Arrowweed.
6. Cottonwood.
7. Desert scrub.

hurriedly without sufficient safeguards to insure reliable data. While much of the data indicate the magnitude of water losses, they did not give the information needed for accurate application to irrigation planning and control measures, or to adequately assess other management alternatives.

In response to the needs for more detailed research in the riparian and phreatophyte zones of the Southwest, a project was set up in 1955 by the Rocky Mountain Forest and Range Experiment Station (USDA Forest Service) at Tempe, Arizona, to intensify the study of (1) ways of measuring and evaluating water losses from the different species in moist-site vegetation, and (2) the ecological relationships of moist-site vegetation to develop optimum management procedures.

For many years, flood-plain management consisted of attempts to control or completely eliminate undesirable phreatophytes for water salvage, even though some thoughts were given to other resource uses (Bowser 1952). More recently, interest has increased in preservation or development of the wildlife, recreation, and esthetic values of these areas. It therefore becomes increasingly important to determine the effects of phreatophyte clearing upon the other resources involved. We can no longer justify rather casually the clearing and destruction of phreatophyte vegetation to save water.

Thus, much more detailed information is needed on the actual evapotranspiration losses from individual plants and from different types of phreatophyte cover, as well as on the ecology and life history of the important

species. Alternate management practices must also be known to properly manage these areas for optimum use of all resources inherent in phreatophyte vegetation.

The value of riparian vegetation along mountain streams is rapidly increasing for various resource uses, particularly those related to recreation. Careful management to allow for increased use without deterioration of the vegetation or water quality is imperative in many areas. Measures to prevent excessive flood damage, trampling of streamsides, and water pollution are examples of the problems facing managers of this zone.

MEASUREMENT AND EVALUATION OF WATER LOSSES FROM MOIST-SITE VEGETATION

The need for proper evaluation of water losses from moist-site vegetation, and of the possibilities of water salvage by vegetation removal or manipulation, require research aimed not only at determining water losses from individual plants under different environmental conditions but also at evaluating stream-reach losses and the effect of vegetation removal.

Measurements of evapotranspiration losses from individual plants started many years ago, often using plants grown in containers. Most of these early studies were limited in scope. With time and experience the containers became more refined and detailed, until very elaborate lysimeters were built which measured changes in the environment and in soil water. However, because it has long been recognized that plants in containers are not growing naturally, many other methods have been tried to determine actual transpiration losses from the individual plant or cut shoot. For instance, the plastic evapotranspiration tent was developed to measure water losses from the phreatophytes. Also in recent experiments, the Scholander pressure chamber "bomb" has been used in riparian vegetation as an indicator of water availability. The bomb, however, does not measure transpiration losses.

Values of many of these approaches for measurement and evaluation of water losses from moist-site vegetation have been discussed by the Pacific Southwest Inter-Agency Committee (1966).

Tanks and Evapotranspirometers

The first major studies to determine water losses from specific moist-site wildland species were done by the use of metal cylindrical tanks varying from 2 to 10 ft in diameter, depending on the species to be studied. In all cases, these tanks were maintained with a specified water table varying from 2 to 6 ft below the soil surface, again depending on the objectives of the study and the species to be used.

Plants grown in small tanks may respond very differently from mature plants in the field. They are subject to very different environmental conditions which affect the water-loss readings. Unfortunately, these tank data are all that are available for many species under different climatic and water-table depth conditions.

The studies started by the California Division of Water Resources in 1927, using willow, cattails, and several species of grasses and rushes, showed that water losses from these riparian plants may be equal or greater than evaporation as measured from a Weather Bureau pan close by (Young and Blaney 1942). Use of water increased markedly as depth to the water table decreased. One of their studies demonstrated that tanks should not be isolated and thereby receive advected heat from the side (Taylor and Nickle 1933). Tules (cattails) grown in an isolated tank lost about three times as much water as those in a tank placed in a dense cover of the same species. This fact was not always considered in later studies or in the evaluation of the tank data relative to water losses from river reaches.

The extensive survey of water resources and water losses carried out cooperatively in the Upper Rio Grande during the middle 1930's (Blaney and others 1938) included tank studies of many agricultural crops and some marshland species but no true phreatophyte or riparian species.

The Pecos River survey in 1939-40 included tanks that were planted to saltcedar, sacaton (Sporobolus airoides), and saltgrass (Distichlis stricta) at Carlsbad, New Mexico (Blaney and others 1942). This installation used small metal tanks large enough for only one saltcedar shrub and not well buffered from the influences of radiation and wind from the sides. There was no replication and the study was run for only one season which did not allow sufficient time for development of the shrubs.

The flood plain of the upper Gila River, Graham County, Arizona, was studied first by Turner and Halpenny (1941) of the U.S. Geological Survey who established tanks near Safford, planted to saltcedar and seepwillow (Baccharis glutinosa). More shrubs were used in each tank but they were not well buffered and were operated for only one season.

A second and more extensive study of the upper Gila River by the same agency included a detailed tank study established at Glenbar,

Arizona (Gatewood and others 1950). These tanks had large single shrubs planted in duplicates at different water-table depths. The readings during the first year are very comparable to the Carlsbad readings. During the second year, however, growth was vigorous and the water losses were very high, probably much too high for typical saltcedar. Unfortunately, the study was terminated by flooding at the end of the second summer. The vigorous second-year growth plus some increased radiation received by partially exposed tanks probably make these readings of water loss too high.

Due to the relatively small size and known inaccuracies of the metal tanks, large plastic-lined evapotranspirometers were designed and built to study water losses from phreatophytes. A block of soil was excavated in alluvium measuring about 1,000 ft^2 in surface area and 8 to 15 ft deep. The hole was lined with heavy plastic. Various means were added to measure the water depth, and to allow pumping and draining of contained water if desired. After these controls were installed, the tank was filled with the excavated soil.

The large area of the research installation and the ability to completely buffer the study plants to a large extent removed the problem of isolation. The elaborate method of adding water to the water table to compensate for evapotranspiration allowed accurate operation and data collection without disturbance of the plant cover. The greater depth of soil and the longer study period produced a more mature cover and a more representative simulation of natural conditions. The greatest difficulty encountered was the accumulation of salt in the water table which, unexpectedly, greatly reduced growth and water losses.

The first of these large plastic-lined tank installations was built in 1959 for saltcedar studies at Buckeye, Arizona, by the Geological Survey in cooperation with the Bureau of Reclamation (van Hylckama 1974). No records of evapotranspiration loss were published until the third growing season. At this time, the cover was nearly mature and beginning to reach the pattern of vigorous spring growth and a more or less dormant summer period. The readings in the Buckeye tanks show a very definite relationship of depth to water table. Saline conditions in the ground water were concluded to have reduced the evapotranspiration losses very markedly.

Another set of large plastic-lined tanks was built in 1961 for saltcedar studies by the Bureau of Reclamation near Bernardo, New Mexico (Pacific Southwest Inter-Agency Committee 1962). These evapotranspirometers were designed to control the difficulties caused by increased salt contents in the soil water. They were flushed yearly to reduce salt effect from accumulations in the ground water. The Bernardo tanks show a different water loss/water-table depth relationship, which appears to contradict some of the other studies. The 3-ft water-table tanks, (2 ft less than the shallowest Buckeye tank) showed rather consistently a reduction not only in water loss but also in the development of a vegetation cover (personal communication, Bureau of Reclamation, Albuquerque, New Mexico).

One interesting result of the Bernardo study was the reaction of the plants to a water-table change from a 5.6-ft depth down to 9 ft. When the water table was dropped rapidly by pumping, the amount of water loss was almost cut in half. In the next year, however, the root system apparently recovered and even at the 9-ft depth it was using nearly as much water as it had at the shallower depth. The tank in which the water table was lowered by plant water use showed a less dramatic reaction.

The Bernardo tanks appear to demonstrate the shallow water-table depths are not optimum for tamarisk, and that when the root system is developed, the water loss from the deeper water tables may be very close to losses from shallower depths if the ground water is reasonably free of excess salt.

There were two other Geological Survey evapotranspirometer installations — one at Yuma, Arizona, which studied arrowweed (Pluchea sericea), saltbush (Atriplex sp.), and Bermudagrass (Cynodon dactylon) (McDonald and Hughes 1968) and one near Winnemucca in northern Nevada which used Great Basin wetland species (Robinson 1970). The results of the latter are not considered applicable in the phreatophyte areas of the Southwest.

Based on the tank data, a mature, dense, unbroken stand of saltcedar growing in the Buckeye area without excessive salts in the soil will utilize 6 to 7 ft of water per year. At the elevation of Glenbar and Safford, Arizona, the figure is probably in the neighborhood of 5 to 6 ft per year. At Carlsbad, the water loss is probably about the same or slightly less. At the higher elevations of Bernardo, the annual water losses would be about 4 or 4.5 ft.

These figures are not conclusive, of course, but they are reasonably consistent. These losses are for dense, mature saltcedar which usually constitutes a relatively small proportion of a flood-plain area. As the vegetation is reduced, the water losses are likewise reduced, so that a comparatively small portion of a flood plain would consume these high amounts of water.

All studies comparing grass with saltcedar used tanks maintained at shallow water-table depths. At these depths the water loss includes a large percentage of evaporation from the soil. Saltcedar growing where the water is close to the surface does not mature into a vigorous stand. Likewise, grass does not develop at water tables optimum for saltcedar growth. Thus, direct comparisons are difficult.

In conclusion, these tank data, in spite of their weaknesses and perhaps inaccuracies, are the most detailed that are available on water losses from saltcedar. In other vegetation types, measured water losses from the tanks have been carefully compared with losses computed by various energy-budget and other types of approaches (van Bavel 1966). These results show that a carefully controlled tank or lysimeter is the only way known at present to accurately and completely measure the water losses from a plant or group of plants (Harrold 1966). Consequently, unless newer techniques prove satisfactory, use of the tank approach will continue to be desirable if more detail is necessary on the actual water losses from phreatophyte vegetation. Carefully designed instrumentation may produce better and faster results at less cost in the long run than initially cheaper and less accurate types of research efforts.

Application of Tank Moisture-Loss Data

Tank data were often used directly to estimate water losses from flood plains (National Resources Committee 1938, National Resources Planning Board 1942, Gatewood and others 1950). Because the tank data, however, were only for a limited set of conditions, it was reasoned that water loss could be predicted from any area if values and vegetation response were known. For many years, attempts have been made to predict moisture losses solely from environmental factors. Essentially these approaches utilize a basic formula which states the relationship of evaporation of water to energy from the sun. Some of these formula approaches are very simple and include only temperature and day length. Later formulas use additional factors such as humidity, wind movement, radiation, and vegetation response (Criddle 1966, Jensen 1966, Cruff and Thompson 1967).

Probably the most widely used approach, especially in river basin studies in the West, is the Blaney-Criddle formula (Blaney 1952a, 1952b; Blaney and Criddle 1962). Essentially it is similar to other formulas (Thornthwaite and Mather 1957, Penman 1963), but requires a crop or vegetation factor (K) as well as information on temperature and day length. As originally prepared by Blaney and Morin (1942), humidity was also used but this factor was dropped in the more recent applications. The energy factor is computed from temperature and day length. The vegetation factor (K) varies with such factors as species, percentage of cover, and season; to a large extent it is based upon data from tank studies. The Blaney-Criddle method has many of the weaknesses of the other empirical formulas but it is simpler and, if vegetation data are available, predictions are usually closer to the actual water loss than by any other formula. Rantz (1969) improved the applicability of this formula to phreatophyte areas.

Evapotranspiration Tent

Very little work has been done with the measurement of transpiration directly from phreatophyte plant parts, with the exception of the development and use of the evapotranspiration tent. This method, developed by the USDA Forest Service at Tempe, Arizona, was used first as a laboratory procedure for measuring the transpiration of potted plants under controlled light, humidity, and temperature (Decker and Wetzel 1957). Air was forced into the chamber containing the plant and the change in humidity between the inlet and the outlet was measured by an infrared gas analyzer which served as an accurate hygrometer. This method worked very well in the laboratory under uniform temperature and light conditions.

A field apparatus was developed with a frameless cylindrical 10- by 10-ft tent made of transparent plastic film. This film was thrown over the plant and inflated by ventilating blowers. The humidity of the airstream entering and leaving the tent was again measured with the infrared analyzer, which was later replaced with a more simple hygrometer. Field observations were made along the Salt River near Granite Reef Dam, Arizona, on transpiration rates of isolated shrubs of tamarisk surrounded by Bermudagrass sod. Evapotranspiration of tamarisk-Bermudagrass stands increased linearly with the amount of tamarisk, with the larger shrubs using two to three times as much water as Bermudagrass sod (Decker and others 1962).

Campbell (1966) compared undisturbed tamarisk shrubs in a high water-table grassy site with those cut at 1 ft from the ground, and found that evapotranspiration decreased approximately 50 percent due to cutting. These results are similar to those from the shorn Buckeye tanks reported by van Hylckama (1970).

The artificial microclimate formed by the enclosed evapotranspiration tent became apparent in a study on the Gila River west of Safford, Arizona; mesquite (Prosopis juliflora) and tamarisk shrubs growing with deep water tables were defoliated after 8 hours inside the evapotranspiration tent. This indicated a very serious enclosure effect which had not been apparent in the Salt River studies where high water tables and, therefore, sufficient surplus water kept the plants alive. Mace (1968) redesigned the evapotranspiration tent to increase the amount of ventilation because he determined that the serious enclosure effect was due in part to poor ventilation inside the tent rather than entirely to the greenhouse effect of the plastic. However, there is still a serious question about the use of the evapotranspiration tent and its effectiveness in determining rates of water loss in the field, even though Decker and others (1962) felt that the enclosure effect would be more or less similar when rates of transpiration between species were being compared. The enclosure effect has been questioned by Lee (1966) and again by Mace and Thompson (1969).

Sebenik and Thames (1967) used the tent modified by Mace in 1966 to measure evapotranspiration from tamarisk on the San Pedro River. Their water-loss figures are among the highest published, probably due in large part to the enclosure effect.

As a result of these studies, the evapotranspiration tent is not now recommended until the enclosure effects have been critically evaluated.

Heat-Pulse Meter

Swanson (1962) helped develop instrumentation for detecting the movement of sap in the stems of conifers. A correlating run with the evapotranspiration tent (Skau and Swanson 1963, Decker and Skau 1964) indicated sap flow might possibly be used to measure the rate of transpiration. One difficulty, and as yet unresolved, is the determination of the amount of moisture moving upwards in the stream of water because the instrument records only the rate of movement, not the amount which is flowing. Unfortunately, the heat-pulse meter is better adapted to use in conifers than in hardwood species because of the greater homogeneity of wood of conifers, but by using more sampling points, the technique was thought to be applicable to measurement of sap flow in hardwood. Forest Service results indicate, however, that variability of sap flow is too great. Sap velocity in mesquite is highly variable from hour to hour, and appears to lag actual transpiration well into the night.

Because of these environmental influences and apparent inherent variability of sap flow it can be concluded that in mesquite, and perhaps in all hardwoods, techniques of integrating a number of sap-velocity measurements in the cross section of a trunk are too crude to warrant interpretations of transpiration rates.

Pressure Chamber

Considerable work has been reported in recent years on techniques for determining moisture stress in plants. The use of the pressure-bomb technique in watershed management research is now being evaluated by the Forest Service. The pressure bomb (Scholander and others 1964, 1965; Boyer 1967, Kaufmann 1968) appears to be an effective field and laboratory method for determining an index of leaf-water potential and internal water stress of some plants. The technique consists of placing a leafy shoot, or single leaf, inside a steel chamber with the cut end exposed to the atmosphere. Pressure of dry nitrogen is increased within the chamber until xylem sap begins to bubble out from the cut end, at which time the pressure is recorded. This technique is particularly suited to field conditions because of rapidity of measurements, and low cost and dependability of equipment (Waring and Cleary 1967). Because the pressure needed to force water from leaf cells to the cut xylem surface is basically a function of leaf-water potential, predawn pressure-bomb readings can be considered an index to soil-moisture availability within the root zone.

Bomb measurements are influenced by osmotic potential of the xylem sap, resistance to xylem movement of water, loss of water to voids in the xylem, the rate nitrogen is released into the pressure chamber, precision of the low-pressure gage, and elapsed time between twig removal and bomb reading (Campbell and Pase 1972). Even with these sources of error, a high degree of consistency between successive readings is usually characteristic of the bomb technique because the internal plant-water status tends to integrate the effects of myriad environmental factors. For example, if soil moisture is limiting but atmospheric stress is low, then the bomb reading will also be relatively low. A change of either parameter, however, will cause the bomb reading to change. Other environmental influences such as vapor-pressure deficit, wind, temperature, phenology, and physiology are integrated into every bomb reading. Bomb data are not repeatable with the same degree of consistency within and among all species; there-

fore a precursor to any "bomb" study is species selection.

The pressure-bomb technique to determine water requirements appears to be a useful tool in watershed management. While this instrument does not give the amount of water being lost, it can readily segregate those plants which have water available to them and are obtaining their water from the deeper water supplies during a period of drought. Thus, vegetated areas with available water can be readily determined by use of this technique. In a central Arizona chaparral community, the pressure chamber was used to evaluate moisture-stress changes in birchleaf mountainmahogany (Cercocarpus betuloides) under several pruning regimes (Campbell and Pase 1972). Removal of 22 and 36 percent leaf mass of mountainmahogany had little effect on plant-moisture stress. Removal of 41 and 66 percent leaf mass caused highly significant decreases of 6 and 8 bars tension, respectively. Based on this reduced internal plant-moisture stress, it is assumed that water will not be removed from the soil as rapidly or in as large amounts as occurred before pruning.

Phreatophyte Flood-Plain Reaches

Research in phreatophyte water losses was aimed at determining the effect of vegetation clearing upon water yield. Because of the high cost of research studies, many early attempts were made to use indirect methods to estimate savings.

Data from tanks planted to phreatophyte species have been widely used for this purpose. Sometimes the amount of possible water salvage has been increased by using the maximum figures of water loss from tanks. Gatewood and others (1950), averaging six different methods, estimated that total use of water along a section of the Gila River in Graham County, Arizona, during a study in 1943 and 1944 was 28,350 acre-ft (including precipitation) of water from 9,303 acres of bottomland vegetation. This amounts to about 3 acre-ft per acre of phreatophytes. Data derived from the Glenbar tank study (one of the six methods used) indicated that the total water loss was approximately 18.7 percent higher than the average of the six methods. Inasmuch as saltcedar was the principal vegetation, the high water-loss figures obtained from the saltcedar tanks could explain the high estimate of water loss by this method. The authors state that a large percentage of the water loss could be saved by clearing the phreatophytes, but they made no estimate of the actual amounts.

Turner and Skibitzke (1952) estimated that the clearing of a 2,000-ft channel along the Salt and Gila Rivers in Arizona would save somewhat less than 1 acre-ft per acre.

In contrast, Blaney and others (1942) concluded from the short-lived tank study at Carlsbad that saltcedar along the riverbeds would use 6 ft of water per year and, away from the river, about 5 ft. This figure was used in the hearing on the proposed phreatophyte control along the Pecos River. Testimony was given that phreatophytes, principally tamarisk, would consume 5 to 6 acre-ft of water, and about half of this water could be saved by clearing (U.S. Senate 1963).

Unfortunately, there are few actual figures of water savings after phreatophyte clearing. However, a recent study conducted along the Gila River in Graham County, Arizona, gives some preliminary indication of amounts of salvage (Culler 1970). In one study reach, 1,720 untreated acres lost an average of 21 acre-ft of water per day for a 6-month period (February through July), or an average water loss of 2.2 acre-ft per acre. Even assuming that water loss would be less for the August through January period, the measured water loss is still somewhat more than the 3.0 acre-ft per acre per year estimated as total water loss for approximately the same reach by Gatewood and others (1950).

Subsequently, the study reach was completely cleared and computed evapotranspiration declined to 13 acre-ft per day, a water savings of 8 acre-ft per day or an average of 0.8 ft depth per acre for the 6-month period. Only 45 percent of the area was under dense phreatophyte canopy of tamarisk and mesquite, with the remainder open vegetation. Even if this amount of water savings is credited solely to the area of dense cover, the amount would be only 1.8 acre-ft per acre of cleared dense phreatophyte vegetation, far less than 2.5 to 3.0 acre-ft estimated for the Pecos River (U.S. Senate 1963) at approximately the same climatic conditions. The actual savings probably was closer to 0.8 than 1.8 acre-ft, and this amount would decline as replacement vegetation became established (Culler 1970).

Riparian Reaches

Only a few estimates of evapotranspiration have been obtained from riparian reaches, and these data, like phreatophyte water-loss data, are not necessarily transferable to other sectors (table 1). Plant-species diversity (frequency, composition, and age) and highly variable environments create a situation where no completely satisfactory method has been developed.

Table 1.--Summary of studies in elevation zone below 4,300 ft, with estimate of ET (evapotranspiration) per acre of flood plain

Reach, elevation range, and area	Length of channel	Dominant vegetation type	Depth to water table	Estimated ET per acre of channel	Savings after treatment	Comments
	Miles			*Acre-ft*		
SYCAMORE CREEK						
(1,400-1,760 ft) 1,400 acres	10	Mesquite-burrobrush	20 ft (approximate)	1.1	--	Inflow-outflow technique, vegetation not treated.
AGUA FRIA (1,600-4,000 ft) 3,230 acres	61	Mesquite	0-2 ft,(36%) 5-6 ft,(22%) 10-20ft,(42%)	1.8	--	ET estimated on basis of depth to ground water and areal density. Vegetation not treated.
COTTONWOOD WASH (4,000-4,300 ft) 22 acres	1.5	Cottonwood	2-3 ft	3.6	1.7	Inflow-outflow technique, vegetation eradicated on one sector. Control sector above treatment area.
MONROE CANYON (2,000-2,500 ft) 38 acres	1.3	Oak, maple, bigcone Douglas-fir, alder, willow		4.2-5.0	.5	Paired watersheds, Monroe Canyon vegetation treated following calibration period; Volfe Canyon used as control watershed.

In certain areas, stream-gaging stations have been used above and below stream reaches. A water-budget analysis can then be used to estimate evapotranspiration by total inflow minus outflow, corrected for such factors as deep drainage and soil-moisture storage (table 1).

Thomsen and Schumann (1968) used the water-budget analysis to study water resources of Sycamore Creek, Maricopa County, Arizona. In a 5-year period, water-budget analysis indicated water loss from the channel on the lower 10 miles of Sycamore Creek averaged 1,500 acre-ft. In this channel and flood plain, riparian vegetation covered about 1,400 acres, with denser vegetation in the lower half where depth to the water table was usually less than 20 ft. In the upper half of the area where the vegetation was less dense, the water table was generally more than 20 ft deep. Average evapotranspiration loss from the 10-mile reach was estimated to be 1.1 acre-ft per acre; of this, transpiration rather than evaporation probably accounted for most of the loss. Thus, a large percentage of this loss would, perhaps, be saved following vegetation removal.

Anderson (1970) measured channel losses from a natural flow regimen in part of the Agua Fria drainage, and estimated maximum possible losses that might result in the same reaches if additional water became available as a result of modification of upland chaparral vegetation. His theory was that the watershed treatment would increase streamflow and raise the level of ground water. This increased flow would cause increases in flood-plain vegetation density and thus evapotranspiration losses would increase. Also, the additional water would change the flow regimen in some channel sectors from ephemeral to perennial. Results indicate the 61 miles of reach contained about 3,230 acres of variously vegetated flood plain, including many acres classified as bare soil. Present annual evapotranspiration losses were estimated at 5,750 acre-ft or about 1.8 acre-ft per acre of channel and flood plain. If the expected increase in water yield occurs, Anderson estimates total possible water loss from this zone would reach nearly 3 acre-ft per acre per year.

Bowie and Kam (1968) used soil-water budget analysis and transpiration-well data on Cottonwood Wash in northwestern Arizona to indicate effects of removing riparian vegetation from a 1.5-mile section of stream channel. The average amount of water saved after removing about 22 acres of cottonwood (Populus fremontii), willow (Salix sp.), and seepwillow was estimated at 1.7 acre-ft per acre, or a savings of 6 percent of inflow. Transpiration-well data indicated vegetation eradication near the shallow wells may reduce water use by as much as 90 percent. Re-

growth of shrub-type vegetation, such as seep-willow, reduced the water savings effected by the removal of tree-type vegetation. Water quality did not change significantly downstream following treatment.

Watershed studies in the woodland-riparian zones of Monroe Canyon in the San Gabriel Mountains of southern California exemplify a successful application of water-budget analysis and effect of vegetation treatment (Rowe 1963). Volfe Canyon, an adjoining untreated watershed, was used as a control. Along the lower reaches of Monroe Canyon, 38 acres of woodland-riparian vegetation was removed; of this, only about 3.8 acres were riparian species with the rest composed of woodland species common to adjacent canyon slopes. Following treatment, the flow from Monroe was 17.4 acre-ft more than would have occurred had it not been treated. This increased yield was about 0.5 acre-ft per acre treated. Chemical analysis revealed no changes in chemical content or total solids due to treatment. Removal of canyon-bottom vegetation and the resultant insolation of the stream channel did result in an appreciable higher concentration of green algae, especially in the summer. Rowe stipulates conditions necessary for increased water yields to occur: (1) water supply must be adequate to exceed evapotranspiration losses after treatment, (2) the water table or zone of saturation must be within reach of the heavy water-using woodland-riparian vegetation, and (3) the canyon-bottom soils overlaying the water table must be of sufficient extent and depth to permit reduction in evapotranspiration if the deep-rooted vegetation is eliminated.

The few riparian treatments performed indicated rather consistent increased water yields were obtained following riparian treatments. Two reach studies (table 1) indicate a water savings of about 1.1 acre-ft per acre after removal of flood-plain vegetation. Two other studies predicted that reduction of evapotranspiration losses of about the same amount might occur if the denser vegetation on the flood plain were removed. In summary, a working hypothesis somewhere between 1 and 2 acre-ft of water savings is as close an approximation as possible with the limited data available. These water yields would have to be weighed against losses or gains from other resources such as wildlife habitat and food, fish habitat, recreation, and esthetics for evaluation of possible benefits (Campbell 1970).

Ground-Water Wells

Ground-water wells have often been used to evaluate evapotranspiration losses from flood-plain reaches. These data indicate the changes in water level, which can be interpreted to give rough estimates of the ground-water losses by phreatophytes. However, the data are subject to wide fluctuation due to the characteristics of the alluvial material in which the ground water occurs. It is recommended that ground-water wells be used only for monitoring changes in the water-table levels and to evaluate the success of clearing operations. It is doubtful that they will give an accurate indication of the amount of water losses. In most studies, there have not been sufficient wells to give a good statistical indication of changes and some of the studies have been severely criticized because the conclusions were reached with too few wells.

Theis and Conover (1951) proposed that a series of ground-water wells could be used to determine water losses in an area of phreatophytes. They would first measure the normal ground-water conditions then remove the phreatophytes and determine water-level changes. The next step would be to pump the water out to equal the water losses of the plants and measure the rate of pumping. Tests of this type on the Salt River showed that removal of saltcedar did reduce diurnal fluctuations (Gary 1962). Later, thirty-nine 3-inch wells within a 20-ft radius were installed, but variation between wells was too great to accurately measure the rapidly changing ground-water level created by pumping (Gary and Campbell 1965).

Use of Energy Measurements

Energy measurements have often been used to determine evapotranspiration losses and it has been found possible, with the use of sophisticated and expensive instruments to accurately predict the amount of evapotranspiration losses from homogeneous vegetation surfaces. The different methods and approaches are thoroughly discussed in Conference Proceedings of both the American Society of Civil Engineers (1966) and American Society of Agricultural Engineers (1966).

Unfortunately, comparatively little work has been done in forest or other irregular or discontinuous types of cover. In phreatophyte areas, research is needed to determine the so-called "oasis effect" — the advective energy relationships between the transpiring area and the surrounding desert or semiarid climate. These irregularities of energy input and output are extremely difficult to evaluate. There is no present research which studies these phenomena in relation to phreatophyte cover, but the results of the studies on agricultural cropland would indicate that there should be possibilities

of determining evaporation losses from larger areas of phreatophyte vegetation. Likewise, there are possibilities of developing methods such as remote sensing, laser beams, and infra-red film to measure moisture content of the air surrounding the phreatophyte zone. Research should be pushed aggressively in search of new approaches.

ECOLOGICAL RELATIONSHIPS

To properly manage riparian and phreatophyte zones requires a knowledge of (1) the present community relationships, (2) the possibility of developing different vegetation types, and (3) the individual reactions of the various species that occupy the zone or that might be introduced under management.

Community Changes

As has been pointed out previously, drastic changes have occurred in the vegetation of the moist-site areas of Arizona and New Mexico. Changes in land use and water regime have been marked with striking results on many of the vegetation communities, particularly flood-plain areas.

Phreatophyte Flood Plains

The original vegetation of the flood-plain areas was dependent primarily on the nearly continuous water supply available to plant roots. Records and reports from early travelers indicate the rivers flowed rather constantly and the water tables were high in much of the valley areas. In the more saline areas were large patches of salt-tolerant grasses, surrounded by saltbushes and other salt-tolerant plants.

The early pioneers used the cottonwood, mesquite, and other trees and larger shrubs for fuel and building materials. In the Arizona desert, the lands dominated by mesquite were some of the best soils in the valley and were soon cleared for farming. Along the Rio Grande, the first and finest farmland was created by removal of cottonwood.

The Old World tamarisk, or saltcedar, found conditions ideal for rapid invasion of the flood-plain areas. First introduced into the United States as an ornamental, tamarisk was sold at nurseries in the East as early as 1823 (Horton 1964). By 1856 it was being sold in nurseries in California. In 1901, it was recorded as a naturalized shrub along the Salt River at Tempe. In the early 1900's, Thornber (1916) stressed the desirability of using Tamarix of several different species around buildings, for hedge rows, and in general plantings in the hot desert areas.

Tamarisk growing on the flood plain of the Gila River near Safford, Arizona.

In the 1920's, saltcedar was beginning to spread along the Rio Grande, and other rivers such as the Gila, Salt, Pecos, and Colorado (Robinson 1965). By the 1940's, these river flood plains were to a large extent covered with a solid, unbroken stand of almost impenetrable saltcedar. Now it is found along many smaller streams, around springs, by roadsides, and in other areas that have sufficient moisture to germinate and establish the seeds.

Along some flood-plain reaches, dropping water tables have reduced the stand of saltcedar, because ground water is now apparently out of reach of its roots. In the Phoenix area, where in the 1940's a dense stand of saltcedar extended along the Salt River from east of Mesa through Tempe and Phoenix to the junction with the Gila, the shrubs are now growing as widely spaced desert-type plants. The remaining shrubs depend on floodflows or rain for survival. In dry periods, these shrubs will make almost no growth, and tend to drop their leaves. They leaf out very quickly when water becomes available, however. Fires burning through these areas kill a fairly large number of plants and create an even more open stand. It is probable, in this desert climate, that the shrubs must be spaced 15 or 20 feet or more apart to be able to have sufficient root systems to withstand lengthy droughts. A heavy, dense stand will survive only where the water tables are within 15 or 20 ft of the surface. Much of the lands originally dominated by saltcedar have also been converted into farms or industrial use near the towns and cities.

In spite of the major changes along the flood plains of the Southwest, there are still

large areas occupied by wildland vegetation, but usually altered by man. Marks (1950), who studied the vegetation and soil relations of the lower Colorado desert, included considerable information on the communities along the lower Gila River. At that time, the bottom lands were dominated by an arrowweed-saltcedar community with other species such as seepwillow, screwbean mesquite (Prosopis pubescens), and saltbush. Along the river channels, cottonwood and willow were found. Scattered through the valley bottoms were saline communities dominated by Sueda and Allenrolfea. Above the bottom land occurred the most conspicuous of the valley communities — that dominated by mesquite. These lands are usually suitable for farming, and therefore a large percentage has been cleared. Mixed with the mesquite or at somewhat higher elevation was a community of Atriplex polycarpa.

Haase (1972), in his study of the lower Gila River, indicates that saltcedar occupies about 50 percent of the total bottom-land area. Under present conditions he feels that this dominance will not be changed unless there is some marked fluctuation in the water table or in other environmental conditions. His analysis and breakdown of the communities is very similar to Marks (1950).

Somewhat similar communities were studied along the Salt River above Granite Reef Dam east of Tempe (Gary 1965). The saltcedar communities were separate and distinct from the arrowweed, and occupied sites with shallower water tables and a silt loam soil, contrasted to the sandy loam found under the arrowweed and mature mesquite. Though there are a few cottonwood trees, these were not significant enough to be included in the analysis.

Along the Rio Grande, Campbell and Dick-Peddie (1964) found that saltcedar was the major dominant in southern New Mexico, but as one progressed up the river there was more cottonwood, Russian-olive (Elaeagnus angustifolia), and other species. These authors observed that cottonwood assumes dominance over saltcedar if cottonwood is left to develop into a full tree without disturbance. In mature stands of cottonwood, saltcedar grows only in natural openings and along the outer edge of the cottonwood stand.

Mesquite Washes

Many ephemeral streams below 3,500 ft contain broad alluvial flood plains and terraced bottoms that support high densities of deep-rooted trees and shrubs such as mesquite, blue paloverde (Cercidium floridum), catclaw acacia

Old mesquite growing near Granite Reef Dam, Arizona.

(Acacia greggii), burrobrush (Hymenoclea monogyra), and wolfberry (Lycium andersonii). These ephemeral streams, arroyos, and dry washes, predominately lined with mesquite, provide a certain amount of protective cover for cattle and wildlife. However, the deep-rooted trees also remove unknown quantities of water from the water table. Since the trees depend on deep water supplies, removal of the trees would eliminate transpirational losses from the aquifer. On-site precipitation, which is usually less than 15 inches, would continue to be lost because of high soil-surface evaporation.

Mesquite in some areas may be extensive enough to warrant commercial harvesting. Mesquite makes excellent charcoal briquettes and is one of the better fireplace woods. A minor use of mesquite wood is for fenceposts.

From 2,500 to 3,500 ft, cottonwood and sycamore sometimes codominate with acacia and mesquite, forming an almost impenetrable understory. These trees use water from alluvium supplies but also provide channel stabilization and potential recreation sites.

Cottonwood Communities

Riparian communities between 3,500 and 7,000 ft, in general, contain the greatest number of species, the greatest percentages of cover, and will probably require the most planning before sound management practices can be developed. Cottonwood, ash (Fraxinus pennsylvanica), sycamore (Platanus wrightii), oak (Quercus sp.), and walnut (Juglans major) are typical trees in this sector.

Cottonwood reaches its maximum density in these altitudes in the alluvial valleys, such as the Verde River, Cottonwood Wash, and

Cottonwoods growing in dense stand along the Verde River in Arizona.

Carrizo Creek, Arizona. Most of the vegetation in large valleys was extensively altered in pioneer days for fuel and building materials.

Composition of streamside vegetation is continually changing. On the Rio Grande, Wislizenus 1847), Abert (1848), Gregg (1856), Metcalfe (1902), Watson (1912), and Campbell and Dick-Peddie (1964) all indicate successive changes in vegetation, primarily because of the influence of man. Watson (1912) reported the cottonwood trees were small because native ranchers used the wood for fuel. The growth rates and number of tree species were apparently not sufficient to supply the demand created by the localized settlers at this time. Construction of dams, irrigation canals and ditches, and drainage of marshes in the twentieth century have further changed the community complex.

The Santa Cruz and San Pedro Rivers in Arizona and Guadalupe Canyon in southwestern New Mexico are distinctly unique in the Southwest because they form a continuous ribbon of riparian plants from the State of Sonora, Mexico, into the continental United States. Because of a similarity of climate and lack of geographical barriers, many species of birds and reptiles common to Mexico follow these channels into the United States.

Sycamore-Dominated Ephemeral Streams

Along Sycamore Creek, near Sunflower, Arizona, Campbell and Green (1968) subdivided stream-channel vegetation into two major types, riparian and pseudoriparian, with both types extending ribbonlike from 1,500-ft elevations to 5,500 ft. Riparian species are obligate and pseudoriparian facultative. Thus, pseudoriparian species extend from adjacent slopes into the riparian zone where growing conditions are more favorable. Alder (Alnus spp.), willow, cottonwood, and sycamore are examples of riparian species; these plants grow only where additional ground or surface water occurs. Examples of pseudoriparian species are mesquite, oak, and acacia. These plants grow faster and taller on sites where ground or surface water supplements local precipitation, but they also germinate and grow on surrounding hillsides.

On Sycamore Creek, the riparian species are diffused and spread rather evenly up or down the channel. Pseudoriparian species, however, particularly the shrubs, show a distinct zonation along the channel at about the 3,000-ft elevation. Adjacent to the stream and at the same elevation there is an abrupt ecotone between

Sycamores growing along Sycamore Creek near Sunflower, Arizona.

desert and chaparral vegetation types. Most shrub species have a wider ecological amplitude than trees with respect to variation in soil moisture. Ninety-five percent of the shrub species occur on both relatively mesic and xeric sites, and are thus classified as pseudoriparian, versus only 52 percent of the trees.

Manmade disturbances in this zone are relatively minor. The frequent floods have a greater effect. Disturbances in the flood-prone channel cause species to form mosaics of seral stages of communities, with different combinations of species dominating each stage.

Perennial Streams

Canyons of the major rivers, including the Colorado, Rio Grande, Salt River (above Roosevelt Reservoir), and the Gila (above the confluence of the Blue), have thin strips of vegetation along the edges composed of some scattered trees but mostly shrubs including saltcedar. Floodflows remove young trees and shrubs at periodic intervals, but reestablishment is rapid. Due to the large ratio of open water to vegetation, however, transpiration causes a minor percentage of the total water losses and, therefore, management of vegetation for water savings could rarely be justified.

Side streams at the higher altitudes are usually alder dominated. Most of them are not altered by man except for recreational use, development of campgrounds and roads, and fishing.

Alders lining the streambanks of Oak Creek Canyon near Sedona, Arizona.

Species Characteristics

An important characteristic of any species in its relation to the community is its ability to establish itself naturally (or after planting, if an introduced species). Many phreatophyte species, such as saltcedar, cottonwood, and willow, are spread primarily by abundant windborne seeds. When they fall on water or moist soil they can germinate quickly. Seeds of these species will usually lose viability rapidly and unless they germinate within 2 to 4 months will lose their capacity to do so (Horton and others 1960). Though the seed will germinate very rapidly, the new seedlings require wet soils for several weeks to be able to develop sufficient roots for survival. These species thrive best in an open situation such as along sandbars or areas disturbed by floodflows and, when conditions are ideal, invasion will be rapid.

Seed germination of mesquite and associates is not dependent on such rigid soil-moisture conditions. While germination may be started by floodflow, especially in gravel washes, they seem to be spread more by cattle and rodent activity (Glendening and Paulsen 1955). Thus, mesquite has spread into the grassland and hillsides of southern Arizona where summer rains are more frequent (Schuster 1969). In the drier areas of central Arizona, however, the species is more common above deeper ground-water tables.

Root systems of phreatophyte species vary greatly. Mesquite is extremely deep rooted; Kearney and Peebles (1951) report it penetrates as much as 60 ft into the alluvium. Saltcedar can also be deep rooted. Seepwillow is relatively shallow rooted, growing only where the ground water is close to the surface (Gary 1963).

Arrowweed shrubs send out lateral roots just below the surface of the soil which sprout to form dense clusters over relatively large areas (Gary 1963). Some seedlings of this species have been noted, but it is felt that the dense thickets are caused by lateral spread.

After burning or cutting, saltcedar shrubs redevelop rapidly; the sprouts from the root crown will grow as much as 10 or 12 ft in a year under favorable conditions. In the study of the effect of grazing, cattle removed approximately 50 percent of the foliage produced but the shrubs still grew vigorously (Gary 1960). During the second year the stand became so dense and heavy that cattle would not enter the area.

In another study, Campbell (1966) found that even biweekly cutting of saltcedar at a height of 12 inches above the ground did not kill the plants. However, if all foliage was removed from the stump at 2-week intervals, 92 percent of the plants died the first season and the remainder died after retreatment the following year. Thus, in areas where there is sufficient water and grass, heavy use of saltcedar by cattle is desirable. Because mowed saltcedar grows so rapidly, cattle or sheep must use it excessively to keep the crowns within reach.

All of the aboveground portions of saltcedar will develop adventitious roots and form new shrubs if kept wet in moist soil. Gary and Horton (1965) found that 100 percent of stem cuttings would sprout at all times of the year if they are kept moist and warm. Root cuttings did not sprout. If stem cuttings are allowed to dry, even as little as 1 day, the sprouting ability is very quickly reduced. This rooting ability is important in mechanical clearing because, if the operation is done when the ground is moist, a large portion of the plant parts that are buried will develop new shrubs.

Taxonomy of Tamarix

The taxonomy of saltcedar has long been confused. The first plants introduced into the United States were usually called Tamarix gallica L.; later the nursery catalogs began to carry the name Tamarix germanica L. (Horton 1964). There is no way of knowing what species of plants were actually introduced. The early floras usually listed Tamarix gallica as the introduced species.

McClintock (1951) reported that there were four species of pentamerous tamarisk in the United States. She stated that T. gallica was a rather rare shrub in the West and that the common aggressive western saltcedar should be classified as T. pentandra Pall. rather than T. gallica. She indicated that T. chinensis Lour. was a synonym of T. pentandra. Two other species were listed as ornamentals found occasionally as naturalized plants.

Baum (1967), after extensive study of the genus Tamarix at the Hebrew University, Jerusalem, abandoned the name T. pentandra, and divided the western pentamerous tamarisk (saltcedar) into several species after examining material from various American herbaria. In 1968, the USDA Forest Service at the Forest Hydrology Laboratory started a study of Tamarix taxonomy; individual shrubs were grown from cuttings collected at various locations in the United States and the Old World to check on the growth characteristics and validity of the speciation as outlined by Baum. Their plantings have indicated that while there is variation in the growth habits and phenology of saltcedar, the botanical differences are not significant or constant enough to warrant species separation.

Thus, the aggressive saltcedar should be considered as one species. Due to the fact that the name Tamarix pentandra is not held to be legitimate, another name must be used. The oldest synonym applied to the aggressive pentamerous tamarisk group is Tamarix chinensis; thus by the rules of botanical nomenclature, this name should now be used for the species so commonly naturalized in the West.

OTHER RESOURCE USES OF PHREATOPHYTE AREAS

The emphasis on use and management of phreatophyte areas has recently changed from water salvage to the possible development of other management alternatives. The tangible resource uses, such as the removal of shrubs and trees to develop farmlands or to use these areas for grazing, are relatively easy to justify and to determine the economic values involved. Many intangible resources are very difficult to evaluate, however, including recreation, wildlife, and preservation of natural areas. Determining the most desirable alternative is sometimes very difficult because the resources involved are so often backed by single users who feel that their resource overshadows all the others. Multiple-use management, however, must consider the following resources in addition to water salvage.

Development of Farms and Grazing Lands

Along most of the flood plains, clearing of phreatophyte cover for farm or grazing land has caused the greatest attrition. In many cases, the soils are admirably suited for these purposes even though they can be subject to flooding. This flooding may be alleviated by construction of dams upstream, which allows the farm activity to extend close to the channel. Alkalinity of much of the flood plain now covered by phreatophytes may be too high for farming, however. Where water is fairly close to the surface or can be obtained, grazing is often a desirable use for such lands if woody vegetation is removed.

Wildlife

Phreatophyte areas can provide shelter for game species. Of topmost interest are white-winged and mourning doves. The white-winged dove particularly nests in large numbers in phreatophyte areas in Arizona, and is a valuable hunting resource (Cottam and Trefethen 1968). Dense woody stands of saltcedar provide nesting sites, but the food — as for most wildlife — must be provided in large part from areas outside the flood plains. Large numbers of doves feed primarily on agricultural fields nearby. When these depredations become severe, the farmer, such as in the Gila River Valley around Buckeye, Arizona, often changes his type of crop. To maintain an optimum population of these doves, it may be necessary to provide food for them.

Historically, doves nested in the mesquite bosques which produced much more food than the extensive saltcedar thickets of today (Arnold 1943). Clearing of the mesquite depleted the dove numbers, which were not restored until saltcedar invaded the area.

Game departments have long been interested in using phreatophyte areas as wintering grounds for waterfowl, particularly on the Rio Grande and the Pecos River flood plains as well as along the Gila River in the Buckeye area. The Game and Fish Departments in both Arizona and New Mexico have cleared areas for the production of green forage. A compromise must be made between preserving cover for nesting of doves and removal of cover to produce food for waterfowl and possibly for doves.

Recently, the value of cottonwood and other phreatophytes for nongame birds has been stressed. This form of wildlife use has intangible values which are very hard to evaluate. The highest concentration of birds noted anywhere in the United States has been reported by Johnson (1970) from the cottonwood communities of the Verde Valley in central Arizona. The most birds and greatest diversity of species occurred in areas containing the densest riparian vegetation. Results of Johnson's study indicated that thinning cottonwood for water savings and flood control reduced nesting bird populations as follows:

	Pairs of nesting birds per 100 acres	
	1969	1970
Severely thinned (10.1 trees per acre)	583	524
Moderately thinned (26.0 trees per acre)	963	886
No treatment (46.6 trees per acre)	1,325	1,006

Rare or endangered bird species must be evaluated in any management plan, particularly in the cottonwood stands of southern Arizona.

Other Tangible Values

Other tangible values of the moist-site species include the use of saltcedar stands as a refuge for honey bees, especially during the

season insecticides are being applied to the croplands. Management of saltcedar for honey production needs more research. Colonies apparently must be widely spaced because of the possibility of disease. Spreading the colonies would allow for intervening areas to be managed for other purposes. Mesquite also is valuable for apiaries. Tannin has been listed as a possible resource from saltcedar, but the recent tests would show that these values are comparatively limited and it would not be possible to maintain any sort of an industry using tannin obtained from saltcedar.

Production of fuelwood is probably not very important from saltcedar areas, but is very much so from mesquite bosques and the cottonwood areas. Riparian wood, as a source of fuel, has largely been replaced just as has the wood-burning stoves that originally burned this wood. And now, of the numerous streamside species, only cottonwood and mesquite occur in extensive enough stands to support a timber utilization industry. Cottonwood has been used for pulpwood, wood shavings, crating, boxes, and pallets. In northern Mexico, a small industry presently utilizes cottonwood for wooden bowls and small statues. In Arizona, cottonwood is estimated to occur on less than 8,000 acres; the major concentrations are in the Verde, Little Colorado, and Gila River drainages with present stands too scattered for most commercial concerns (Barger and Ffolliott 1971).

Flood Control

Saltcedar and other species tend to clog channels because the seedlings invade sandbanks and sandbars close to the stream. As they develop a barrier, sediment collects in the heavy stands. Floodflows are then diverted onto the surrounding lands. These diversions tend to spread the woody barriers more widely, which further increases the flooding. Deposition of debris above the delta of a reservoir may be beneficial, however, if it keeps the debris from entering the reservoir and reducing its storage capacity. Another factor that must be kept in mind, especially after clearing, is the possibility of channel cutting after the channel banks are cleared of vegetation. Wind erosion likewise can be serious after clearing.

Recreation

Heavy saltcedar stands are not particularly valuable for recreational purposes; campgrounds are not appropriate mainly because of hot and humid summer days and because of the unpleasant exudation of salt from saltcedar cover, especially on warm mornings. The shrubs are bare during the fall and winter and they are really attractive only for a relatively short period in spring when many are in full bloom. Saltcedar areas could, of course, be converted to other phreatophyte types; for instance, they could be selectively cleared and cottonwood or mesquite allowed to establish. The development of picnic and camping areas is an important recreation use in cottonwood areas. Cottonwoods are appealing and are definitely needed in areas close to roads or where recreational facilities can be established.

Preservation of Natural Conditions

Due to the changes in phreatophyte areas throughout the Southwest, the preservation of natural conditions is rarely a factor. There are mountain reaches in Arizona and New Mexico, however, where canyons have retained their natural ecological balance. The desirability of preserving these areas is very great.

CONTROL METHODS

To establish optimum multiple-use management in phreatophyte areas, some control or manipulation of portions of the vegetation will often be required.

Mechanical

At present, the rootplow seems one of the most successful mechanical methods for control of saltcedar and other small trees and shrubs. The rootplow undercuts the plants and raises them so they dry out rapidly and are killed. Plowing can be done most effectively when the soil is relatively dry (Horton 1960). Large areas have been rootplowed and then usually raked to get the material into windrows so it will not interfere with floodflows. Because rootplowing tends to kill a large percentage of any grass cover mixed with the saltcedar, it may lead to serious wind erosion. Other mechanical methods of removing the brush were described by Lowry (1966).

Where grass is a factor in the understory, a rotary-type mower can cut the shrubs several inches above the ground. This does not kill saltcedar, but grazing can further reduce or control cover. Although larger plants cannot be cut in this fashion, the method is appropriate if the water table is close to the surface and heavy grazing can be applied. Other trees, for example cottonwood and mesquite, can be selectively removed by sawing and applying systemic herbicides to the trunk.

Chemical

Much research has been done on the chemical control of saltcedar (Hughes 1966), but no really satisfactory method has been developed. Translocation is relatively slow, and the sprouting ability of the root crown is such that there is not a good or consistent response to chemical methods.

Antitranspirants

A great deal has been done with the use of chemicals to close the stomata and, therefore, decrease transpiration and water loss on agricultural crops. Most studies have also shown a corresponding decrease in the growth of the plant due to decreased photosynthesis. Brooks and Thorud (1971) evaluated various antitranspirants on saltcedar, and indicated the method has possibilities.

MANAGEMENT APPROACHES

The development of optimum management plans for the alluvial flood plains and riparian reaches of Arizona is complicated not only by the great variety of environmental situations but also by the many conflicting demands on the various resources. For management purposes, the flood plains can be identified and separated into four ground-water levels, which control the vegetation structure. Although soil texture and salinity are also important factors, the relationships of soil characteristics to vegetation cover of the flood plains are not precisely known; thus, optimum management, at present, must be determined primarily by the existing vegetation and knowledge of water-table depth. The riparian reaches in canyons can be separated by altitude and by species dominance for management purposes.

The four flood-plain zones are not precisely separated by water-table depth but there are specific differences between the zones which affect management practices. Due to the abundance of saltcedar, this species is used as a practical means of separating the zones.

Flood-Plain Zone 1
(Very shallow water table — 0-4 ft)

This zone can easily be recognized by the dwarfed and multistemmed saltcedar and the vigorous Bermudagrass or saltgrass cover. No specific water table depth can be given, but it is generally less than 3 or 4 ft. Along some streams this particular zone is not developed because the stream or delta banks are several feet above the water table.

Grazing and flood passageways would in most cases be the optimum use of the zone. Water savings would be small if the saltcedar were removed. Wildlife use would be minimal because the shrubs are not high enough for nesting purposes. The shrubs could be periodically cut with a rotary mower to maintain this zone. Grazing would tend to keep the plants under sufficient control to minimize maintenance costs.

In summary, zone 1 can usually be managed for grazing and flood control without expecting any appreciable water savings or revenues from other resources. If the water table is lowered by pumping or water diversion, the area should be reclassified to zones 2, 3, or 4.

Flood-Plain Zone 2
(Shallow water table — 4-8 ft)

The water table is shallow enough in this zone to be readily available to the roots of any grass, but not so shallow as to restrict growth of saltcedar. During summer rainy periods many grasses establish themselves in this zone. The water-table depth would be roughly between 4 and 8 ft, depending on soil characteristics.

There are many conflicting uses for this zone. The saltcedar stand is desirable for wildlife purposes or, in some areas, as a haven for bees. But saltcedar can also be removed and the water thus saved utilized either by pumping to irrigate on-site replacement vegetation or allowed to increase river flow an unknown amount for off-site use.

On-site use of the salvaged water could be directed to beneficial resources such as grazing areas or winter food for migratory waterfowl or summer-maturing grain for doves. The habit of the white-winged dove to nest in colonies, even in uniform cover, would it seems, allow clearing of a portion of the saltcedar without appreciably affecting the dove population. Moreover, the bird's dependence on agricultural crops for food seems to be a more determining factor in its numbers than nesting space.

It is probable that partial clearings of saltcedar in strips or patches would save enough water for production of wildlife food. Optimum management is the easiest in this zone with its relatively shallow water table, and both wildlife and better land utilization can be provided.

Fires threaten saltcedar areas. Breaking the heavy stands into blocks would make wildfires easier to control and reduce acreage of destroyed habitat.

Flood-Plain Zone 3
(Medium water table — 8-20 ft)

It is in this zone that the greatest water savings could be obtained by the removal of phreatophyte cover. Practically all of the water consumed by a heavy stand of saltcedar over a water table even as deep as 15 or 20 ft below the surface would be available for salvage if the stand were cleared. The clearing would either raise the water table to make more water available for pumping, or would increase ground-water flow. Many water salvage programs have been designed for this zone.

Unfortunately, this zone also presents serious problems if the saltcedar is removed for water savings. Inasmuch as the water table is too deep for the establishment of Bermudagrass or other species so often found in the shallower water-table areas, the vegetation must be a desert type able to survive on the annual rainfall. In some cases, precipitation is not sufficient to provide a suitable vegetation cover to protect the soil surface from wind erosion and from unesthetic appearance.

Considerable research on replacement cover is needed if the present tree, shrub, and herbaceous cover is removed for water salvage. Many desert species, such as Atriplex, would provide a cover for wildlife and reduce wind erosion if they could be established successfully.

Optimum management of this zone would leave strips or blocks of untouched saltcedar for wildlife between cleared areas for water savings or the establishment of vegetation to provide food for doves and waterfowl. Part of the water saved by the removal of saltcedar could be used for irrigation to establish and maintain a vegetation crop for wildlife food.

Much research is needed in this zone to develop optimum management practices. The value of the salvage water must be determined, and the values of saltcedar for wildlife as well as methods for growing food for doves and waterfowl must also be developed.

Flood-Plain Zone 4
(Deep water table — below 20 ft)

Though roots of mesquite and other desert trees may penetrate down to deeper layers than saltcedar, we have no information on the relative depths of root penetration or on the depths to which saltcedar will be able to extract water. Undoubtedly, there is no definite demarcation between this and the other zones; the 20-ft figure is only a rough approximation. Scattered individuals of saltcedar do grow in alluvial soils that do not receive any moisture other than the annual rainfall or floods. The shrubs are very widely spaced and become dormant during the drier periods but, when rejuvenated by rain or floods, will grow rapidly during the growing season.

Reducing the water table from a zone 3 to zone 4 will kill a large percentage of the saltcedar in a dense stand. Also, because saltcedar is easily killed if burned under drought stress, fires take an additional toll. Much of the Salt River through the Tempe and Phoenix area has been changed to this type of open tamarisk stand. It is far from esthetic and is not particularly used by nesting doves, though quail and other birds may occupy fringes.

Although pumped water could be used to develop a stand or groups of saltcedar, cottonwood and mesquite would be preferable for revegetating this zone if it is desired to provide picnicking and camping sites as well as nesting habit for song birds, such as mourning and white-winged doves.

Streams Below 3,500 Feet

At elevations below 3,500 ft, particularly on the wide flood plains of ephemeral streams and arroyos where deep alluvium occurs and ground water is generally less than about 20 ft, deep-rooted trees and shrubs depend on the subterranean water throughout the growing season. Depending on the porosity of the alluvium, annual recharge, size of the aquifer, and the density of vegetation, this reservoir of ground water will be depleted by evapotranspiration each growing season; streamflow from winter precipitation sometimes, but not always, replenishes the water lost to evapotranspiration. Obviously, removal of the trees and shrubs would eliminate the summer transpirational loss. Water-budget analysis in this zone on lower Sycamore Creek by Thomsen and Schumann (1968) indicated evapotranspiration losses of about 1.1 acre-ft from some 1,400 acres of mesquite and acacia. In this case, the estimated 1,500 acre-ft saved following removal of the deep-rooted trees and shrubs would flow directly into the Verde River without additional costs of pumping or transportation. On flood plains in remote mountain reaches, costs of pumping and transporting the water in a closed system to permanent rivers may be prohibitive; a management alternative is to remove the vegetation and allow the natural channel to transport the increased water yield. In a natural channel, however, expected increased surface water and soil evaporation losses might nearly equal prior losses by evapotranspiration.

Finally, present uses of this vegetated zone —by livestock, small birds and mammals, campers, picnickers, and small-game hunters — will have to be considered carefully before vegetation removal for water-yield increases are initiated.

In narrow canyons in this elevation zone, vegetation is sparse and management to increase water yields is not feasible. These zones could be managed to increase the number of miles of warm-water fish habitat. Also, construction of nature trails would create recreational areas which are currently not utilized by man. Construction of highway "viewpoints" near narrows would improve tourist conception of natural wonders.

Streams Between 3,500 and 7,000 Feet

On a number of flood plains in this elevation zone, selective thinning or removal of undergrowth could improve esthetic appearances and reduce flood hazards. Water savings, if any, from such thinning treatments are not known; in general, vegetation removal of at least 40 percent on watersheds has been necessary to show significant water-yield increases. Neither is the exact extent of losses to wildlife foods and habitats known as a result of selective thinning. Recreation use would increase if the area is accessible by nearby roads. In high-density recreational areas where flooding could cause loss of life or severe property damage, vegetation thinning for flood controls may be necessary. Such thinning should not be so severe as to force abandonment of other on-site uses of the streams, however. Total riparian vegetation eradication for water-yield increases is not recommended because of loss of fish and wildlife habitats and recreation uses.

In narrows, where the channel is mostly cut on bedrock, present uses of the channel are limited to fishermen, hikers and horsemen. Some trails should be relocated away from the streambank to prevent bank sloughing, and new trails should be constructed on ridges away from the stream where erosion is not as severe. Neither vegetation thinning nor complete removal is recommended for water-yield increases because of the generally sparse cover.

Vegetation treatment on small tributaries of major channels offers a distinct opportunity to increase water yields sufficiently to fill small ponds for on-site recreation and wildlife use. Such ponds would improve land utilization, particularly in the chaparral zone, without destroying esthetic values. Development of water for on-site uses should probably become an important management practice.

Streams Above 7,000 Feet

Little, if any, foreseeable change in present management practices is indicated on the high-elevation mountain streams in the Southwest. Neither erosion nor evapotranspiration losses are severe on streams above 7,000 ft Recreation and wildlife use are presently not severely in direct conflict. Erosion control and improvement of fish habitats should have high priority. In general, extensive management should prevail in these zones without change in present management objectives.

Cottonwood Management

Cottonwood, common in the phreatophyte and riparian zones of the upper desert and chaparral areas, once dominated most of the streams and flood plains of the Southwest, even along the rivers where saltcedar now thrives. It is probable, however, that it did not develop readily on the flood plains except in zones 1 and 2, described above. Zone 3 might have had cottonwood if it originally developed under more favorable moisture conditions. It is found at present most commonly along alluvial reaches in the foothill or mountain areas.

Except for limited reach studies, information on water losses from cottonwood areas is lacking but the indications are that losses would probably equal or exceed those from tamarisk.

At the elevations where cottonwood now flourishes, indications are that complete removal of the trees would save 1.5 to 2.0 ft of water. No information is available on the amount saved if stands are only thinned or after other natural growth invades the streams.

A particularly negative feature of cottonwood stands adjacent to farmlands is the clogging of the river channel and diversion of floodflows onto farmlands or other developments. Some undergrowth cutting along a central channel may be necessary to reduce flood hazard. These clearings might be used for recreational areas or to increase grazing.

In spite of these disadvantages, cottonwood stands have important intangible esthetic values, such as the bird life that thrives and develops in these groves. These values of cottonwood must be taken into consideration in the optimum management of our streams.

Thinning cottonwood stands probably would not save much water. It is probable that at least 50 percent or more of the cover would have to be removed before there would be any appreciable savings. Thus, in most cases, management of cottonwood would be determined not by the desire to increase water but by the need for flood control, or the suitability of the

area for recreation or grazing use. Any of these resources could be developed without destruction of esthetic values if sufficient trees are left. However, bird life seems to be reduced in proportion to the amount of thinning.

In both southern New Mexico and southern Arizona, some efforts are being made to improve riparian habitats where peripheral bird habitats lap into the United States from Sonoro, Mexico. Livestock are being excluded in some areas to allow germination and/or resprouting of riparian species in an effort to improve wildlife habitats and to encourage bird reproduction in the area.

Because cottonwood trees grow rapidly, it is relatively easy to establish them wherever there is sufficient water for esthetic or wildlife purposes.

CONCLUSIONS

Optimum management of moist-site areas, whether dominated by saltcedar, cottonwood, or other riparian species, requires careful consideration of both environmental factors and the economic needs of the area. Seldom are areas best managed by devoting the land to a single use, as compromise management will usually return the greatest economic value (Horton 1972).

Only rarely in the Southwest are there phreatophyte areas that would be best managed by complete preservation. Examples are areas of cottonwood and other native species in the southern portion of Arizona, which should definitely be set aside as natural areas.

LITERATURE CITED

Abert, J. W.
1848. Report and map of examination of New Mexico. U.S. Eng. Dep. Rep. on House Exec. Doc. 41, 30th Congr., 1st Sess. 182 p.

American Society of Agricultural Engineers.
1966. Evapotranspiration and its role in water resources management. Am. Soc. Agric. Eng. Conf. [Chicago, Ill., Dec., 1966] Proc. 66 p. Am. Soc. Agric. Eng., St. Joseph, Mich.

American Society of Civil Engineers.
1966. Methods for estimating evapotranspiration. Irrig. and Drainage Spec. Conf., [Las Vegas, Nev., Nov. 1966] Proc. 236 p. Am. Soc. Civil Eng., N. Y.

Anderson, T. W.
1970. Evapotranspiration losses from flood plains in the Agua Fria drainage above Lake Pleasant, Arizona. U.S. Geol. Surv. Open-file Rep. Tucson, Ariz.

Arnold, Lee W.
1943. The western white-winged dove in Arizona. Ariz. Game and Fish Comm. 103 p.

Barger, Roland L., and Peter L. Ffolliott.
1971. Prospects for cottonwood utilization in Arizona. Prog. Agric. Ariz. 23(3):14-16.

Baum, Bernard R.
1967. Introduced and naturalized tamarisks in the United States and Canada [Tamaricaceae]. Baileya 15:19-25.

Blaney, Harry F.
1952a. Consumptive use of water. Definitions, methods, and research data. Am. Soc. Civil Eng. Trans. 117:949-973.

Blaney, Harry F.
1952b. Determining evapotranspiration by phreatophytes from climatological data. Am. Geophys. Union Trans. 33:61-66.

Blaney, Harry F., and Wayne D. Criddle.
1962. Determining consumptive use and irrigation water requirements. U.S. Dep. Agric. Tech. Bull. 1275, 59 p.

Blaney, Harry F., Paul A. Ewing, O. W. Israelsen, Carl Rohwer, and Fred C. Scobey.
1938. Water utilization. p. 293-427. **In** Regional Planning, Part VI — Upper Rio Grande. Natl. Resour. Comm.

Blaney, Harry F., Paul A. Ewing, Karl V. Morin, and others.
1942. Consumptive water use and requirements. p. 170-230. **In** The Pecos River Joint Investigation. Reports of the Participating Agencies. Natl. Resour. Plann. Board.

Blaney, Harry F., and Karl V. Morin.
1942. Evaporation and consumptive use of water empirical formulae. Am. Geophys. Union Trans. 23:76-83.

Bowie, James E., and William Kam.
1968. Use of water by riparian vegetation, Cottonwood Wash, Arizona. U.S. Geol. Surv. Water-Supply Pap. 1858, 62 p.

Bowser, Curtis W.
1952. Water conservation through elimination of undesirable phreatophyte growth. Am. Geophys. Union Trans. 33:72-74.

Boyer, J. S.
1967. Leaf water potentials measured with a pressure chamber. Plant Physiol. 42:133-137.

Brooks, Kenneth N., and David B. Thorud.
1971. Antitranspirant effects on the transpiration and physiology of tamarisk. Water Resour. Res. 7:499-510.

California Division of Water Resources.
1930. Rainfall penetration and consumptive use of water in Santa Ana River Valley and coastal plain. Calif. Dep. Public Works, Div. Water Resour. Bull. 33, 162 p.

California Division of Water Resources.
1933. Water losses under natural conditions

from wet areas in southern California. Calif. Dep. Public Works, Div. Water Resour. Bull. 44, 176 p.
Campbell, C. J.
1966. Periodic mowings suppress tamarisk growth, increase forage for browsing. U.S. For. Serv. Res. Note RM-76, 4 p.
Campbell, C. J.
1970. Ecological implications of riparian vegetation management. J. Soil Water Conserv. 25:49-52.
Campbell, C. J., and W. A. Dick-Peddie.
1964. Comparison of phreatophyte communities on the Rio Grande in New Mexico. Ecology 45:492-502.
Campbell, C. J., and Win Green.
1968. Perpetual succession of stream-channel vegetation in a semiarid region. J. Ariz. Acad. Sci. 5:86-98.
Campbell, C. J., and Charles P. Pase.
1972. Pressure bomb measures changes in moisture stress of birchleaf mountainmahogany after partial crown removal. USDA For. Serv. Res. Note RM-221, 4 p.
Cottam, Clarence, and James B. Trefethen [Editors].
1968. Whitewings. 348 p. D. Van Nostrand Co., Inc., N. Y.
Criddle, Wayne D.
1966. Empirical methods of predicting evapotranspiration using air temperature as the primary variable. p. 54-56. **In** Evapotranspiration and Its Role in Water Resources Management. Am. Soc. Agric. Eng. Conf. [Chicago, Ill., Dec. 1966] Proc., Am. Soc. Agric. Eng., St. Joseph, Mich.
Cruff, R. W., and T. H. Thompson.
1967. A comparison of methods of estimating potential evapotranspiration from climatological data in arid and subhumid environments. U.S. Geol. Surv. Water-Supply Pap. 1839-M, 28 p.
Culler, Richard C.
1970. Water conservation by removal of phreatophytes. Am. Geophys. Union Trans. 51:684-689.
Decker, John P., William G. Gaylor, and Frank D. Cole.
1962. Measuring transpiration of undisturbed tamarisk shrubs. Plant Physiol. 37:393-397.
Decker, J. P., and C. M. Skau.
1964. Simultaneous studies of transpiration rate and sap velocity in trees. Plant Physiol. 39:213-215.
Decker, John P., and Barton F. Wetzel.
1957. A method for measuring transpiration of intact plants under controlled light, humidity, and temperature. For. Sci. 3:350-354.
Gary, Howard L.
1960. Utilization of five-stamen tamarisk by cattle. U.S. Dep. Agric., For. Serv., Rocky Mt. For. and Range Exp. Stn. Res. Note 51, 4 p.
Gary, Howard L.
1962. Removal of tamarisk reduces watertable fluctuations in central Arizona. U.S. Dep. Agric., For. Serv., Rocky Mt. For. and Range Exp. Stn. Res. Note 81, 6 p.
Gary, Howard L.
1963. Root distribution of five-stamen tamarisk, seepwillow, and arrowweed. For. Sci. 9:311-314.
Gary, Howard L.
1965. Some site relations in three flood-plain communities in central Arizona. J. Ariz. Acad. Sci. 3:209-212.
Gary, Howard L., and C. J. Campbell.
1965. Water-table characteristics under tamarisk in Arizona. U.S. For. Serv. Res. Note RM-58, 7 p.
Gary, Howard L., and Jerome S. Horton.
1965. Some sprouting characteristics of five-stamen tamarisk. U.S. For. Serv. Res. Note RM-39, 7 p.
Gatewood, J. S., T. W. Robinson, B. R. Colby, J. D. Hem, and L. C. Halpenny.
1950. Use of water by bottom-land vegetation in lower Safford Valley, Arizona. U.S. Geol. Surv. Water-Supply Pap. 1103, 210 p.
Glendening., George E., and Harold A. Paulsen, Jr.
1955. Reproduction and establishment of velvet mesquite as related to invasion of semidesert grasslands. U. S. Dep. Agric. Tech. Bull. 1127, 50 p.
Gregg, J.
1856. Scenes and incidents in western prairies. 2 Vol. 638 p. J. W. Moore, Philadelphia, Pa.
Haase, Edward F.
1972. Survey of floodplain vegetation along the lower Gila River in southwestern Arizona. J. Ariz. Acad. Sci. 7:66-81.
Harrold, L. L.
1966. Measuring evapotranspiration by lysimetry. p. 28-33. **In** Evapotranspiration and Its Role in Water Resources Management. Am. Soc. Agric. Eng. Conf., [Chicago, Ill., Dec. 1966] Proc., Am. Soc. Agric. Eng., St. Joseph, Mich.
Horton, J. S.
1960. Use of a root plow in clearing tamarisk stands. U.S. Dep. Agric., For. Serv., Rocky Mt. For. and Range Exp. Stn. Res. Note 50, 6 p.
Horton, Jerome S.
1964. Notes on the introduction of deciduous

tamarisk. U. S. For. Serv. Res. Note RM-16, 7 p.
Horton, Jerome S.
1972. Management problems in phreatophyte and riparian zones. J. Soil Water Conserv. 27:57-61.
Horton, J. S., F. C. Mounts, and J. M. Kraft.
1960. Seed germination and seedling establishment of phreatophyte species. U.S. Dep. Agric., For. Serv., Rocky Mt. For. and Range Exp. Stn., Stn. Pap. 48, 26 p.
Hughes, Eugene E.
1966. Research in chemical control of various phreatophytes. p. 19-25. **In** Vegetation Management on Flood Plains and Riparian Lands. Phreatophyte Symp., Pac. Southwest Inter-Agency Comm. 66-3 Meet., [Albuquerque, N. Mex., Aug., 1966].
Jensen, Marvin E.
1966. Empirical methods of estimating or predicting evapotranspiration using radiation. p. 49-54, 64. **In** Evapotranspiration and Its Role in Water Resources Management. Am. Soc. Agric. Eng. Conf. [Chicago, Ill, Dec., 1966] Proc., Am. Soc. Agric. Eng., St. Joseph, Mich.
Johnson, R. Roy.
1970. Tree removal along southwestern rivers and effects on associated organisms. Am. Philos. Soc., Yearb. 1970:321-322.
Kaufmann, Merrill R.
1968. Evaluation of the pressure chamber technique for estimating plant water potential of forest tree species. For. Sci. 14:369-374.
Kearney, T. H., and R. H. Peebles.
1951. Arizona flora. 1032 p. Calif. Univ. Press, Berkeley and Los Angeles.
Lee, Richard.
1966. Effect of tent type enclosures on the microclimate and vaporization of plant cover. Oecol. Planatarum (Gauthier Villars) [Paris] 1:301-326.
Lowry, O. J.
1966. Establishment, operation, and maintenance of phreatophyte control projects. p. 26-36. **In** Vegetation Management on Flood Plains and Riparian Lands. Phreatophyte Symp., Pac. Southwest Inter-Agency Comm. 66-3 Meet., [Albuquerque, N. Mex., Aug. 1966] Proc.
McClintock, Elizabeth.
1951. Studies in California ornamental plants. 3. The tamarisks. J. Calif. Hort. Soc. 12, p. 76-83.
McDonald, Charles C., and Gilbert H. Hughes.
1968. Studies of consumptive use of water by phreatophytes and hydrophytes near Yuma, Arizona. U.S. Geol. Surv. Prof. Pap. 486-F, 24 p.
Mace, Arnett C., Jr.
1968. The influence of climatic, hydrologic, and soil factors on evapotranspiration rates of tamarisk (Tamarix pentandra Pall.) Diss. Abstr. 28(9):3548B.
Mace, Arnett C., Jr., and J. R. Thompson.
1969. Modifications and evaluations of the evapotranspiration tent. USDA For. Serv. Res. Pap. RM-50, 16 p.
Marks, John Brady.
1950. Vegetation and soil relations in the lower Colorado desert. Ecology 31:176-193.
Meinzer, Oscar E.
1923. Outline of ground-water hydrology, with definitions. U. S. Geol. Surv. Water Supply Pap. 494, 99-144 p.
Metcalfe, O. B.
1902. Flora of Mesilla Valley. 28 p. B.S. Thesis, N. M. State Univ.
National Resources Committee.
1938. Regional Planning, Part VI — Upper Rio Grande. 566 p.
National Resources Planning Board.
1942. The Pecos River joint investigation. Reports of the participating agencies. 407 p.
Pacific Southwest Inter-Agency Committee.
1962. Bureau of Reclamation — Albuquerque Development Office. Prototype studies. p. 187-192. **In** Minutes of Phreatophyte Subcommittee, May 23, 1962, Vol. II.
Pacific Southwest Inter-Agency Committee.
1966. Limitations in hydrologic data as applied to the studies of water control and water management. Rep. of Hydrol. Subcomm. 129 p.
Penman, H. L.
1963. Vegetation and hydrology. Commonw. Agric. Bur. Tech. Commun. 53, 124 p. Commonw. Bur. Soils, England.
Rantz, S. E.
1969. A suggested method for estimating evapotranspiration by native phreatophytes. p. 10-12. **In** Geological Survey Research, 1968. U.S. Geol. Surv. Prof. Pap. 600-D.
Robinson, T. W.
1958. Phreatophytes. U.S. Geol. Surv. Water-Supply Pap. 1423, 84 p.
Robinson, T. W.
1965. Introduction, spread, and areal extent of saltcedar [Tamarix] in the western states. U.S. Geol. Surv. Prof. Pap. 491-A, 12 p.
Robinson, T. W.
1970. Evapotranspiration by woody phreatophytes in the Humboldt River Valley, near Winnemucca, Nevada. U.S. Geol. Surv. Prof. Pap. 491-D, 41 p.
Rowe, P. B.
1963. Streamflow increases after removing

woodland-riparian vegetation from a southern California watershed. J. For. 61:365-370.
Schuster, Joseph L. [Editor].
1969. Literature on the mesquite (Prosopis L.) of North America. An annotated bibliography. Texas Tech. Univ., Spec. Rep. 26, 84 p. Lubbock, Tex.
Scholander, P. F., H. T. Hammel, E. A. Hemmingsen, and E. D. Bradstreet.
1964. Hydrostatic pressure and osmotic potential in leaves of mangroves and some other plants. Proc. Nat. Acad. Sci. 52:119-125.
Scholander, P. F., H. T. Hammel, E. D. Bradstreet, and E. A. Hemmingsen.
1965. Sap pressure in vascular plants. Science 148:339-346.
Sebenik, Paul G., and John L. Thames.
1967. Water consumption by phreatophytes. Progr. Agric. Ariz. 19(2):10-11.
Skau, C. M., and R. H. Swanson.
1963. An improved heat pulse velocity meter as an indicator of sap speed and transpiration. J. Geophys. Res. 68:4743-4749.
Swanson, Robert H.
1962. An instrument for detecting sap movement in woody plants. U.S. Dep. Agric., For. Serv., Rocky Mt. For. and Range Exp. Stn., Stn. Pap. 68, 16 p.
Taylor, Colin A., and Harry G. Nickle.
1933. Investigations in the Mojave River area. p. 74-87. In Water Losses under Natural Conditions from Wet Areas in Southern California. Calif. Dep. Public Works, Div. Water Resour. Bull. 44.
Theis, C. V., and C. S. Conover.
1951. Factors for consideration in study of salvage of water used by phreatophytes. In Report to the Saltcedar Interagency Council, Saltcedar Interagency Task Force, Albuquerque, N. Mex. Append. IV. 12 p.
Thomsen, B. W., and H. H. Schumann.
1968. Water resources of the Sycamore Creek watershed, Maricopa County, Ariz. U. S. Geol. Surv. Water-Supply Pap. 1861, 53 p.
Thornber, J. J.
1916. Tamarisks for southwestern planting. Univ. Ariz. Agric. Exp. Sta. Timely Hints for Farmers 121, 8 p.
Thornthwaite, C. W., and J. R. Mather.
1957. Instructions and tables for computing potential evapotranspiration and the water balance. Drexel Inst. Tech. Lab. of Climatol. Publ. in Climatol. 10(3):185-311.
Turner, S. F., and L. C. Halpenny.
1941. Ground-water inventory in the upper Gila River Valley, New Mexico and Arizona: Scope of investigation and methods used. Am. Geophys. Union Trans. 22:738-744.
Turner, S. F., and H. E. Skibitzke.
1952. Use of water by phreatophytes in 2,000-foot channel between Granite Reef and Gillespie Dams, Maricopa County, Arizona. Am. Geophys. Union Trans. 33:66-72.
U. S. Senate.
1963. Phreatophyte control in the Pecos River Basin. Hearing before the Subcomm. on Irrig. and Reclam. of the Comm. on Interior and Insular Aff., May 21, 1963, U.S. Congr. 88th, 1st Sess. 48 p.
van Bavel, C. H. M.
1966. Potential evaporation: the combination concept and its experimental verification. Water Resour. Res. 2:455-467.
van Hylckama, T. E. A.
1970. Water use by saltcedar. Water Resour. Res. 6:728-735.
van Hylckama, T. E. A.
1974. Water use by saltcedar in the lower Gila River Valley (Arizona). U.S. Geol. Surv. Prof. Pap. 655- [In Press].
Waring, Richard H., and Brian D. Cleary.
1967. Plant moisture stress: evaluation by pressure bomb. Science 155:1248-1254.
Watson, J. R.
1912. Plant geography of north central New Mexico. Contr. Hull Lab. 160. Bot Gaz. 54:194-217.
Wislizenus, A.
1847. A tour to northern Mexico. Col. Doniphan's expedition in 1846-1847. Sen. Misc. Doc. 26, 30th Congr., 1st Sess. 141 p.
Young, Arthur A., and Harry F. Blaney.
1942. Use of water by native vegetation. Calif. Dep. Public Works, Div. Water Resour. Bull. 50, 154 p.

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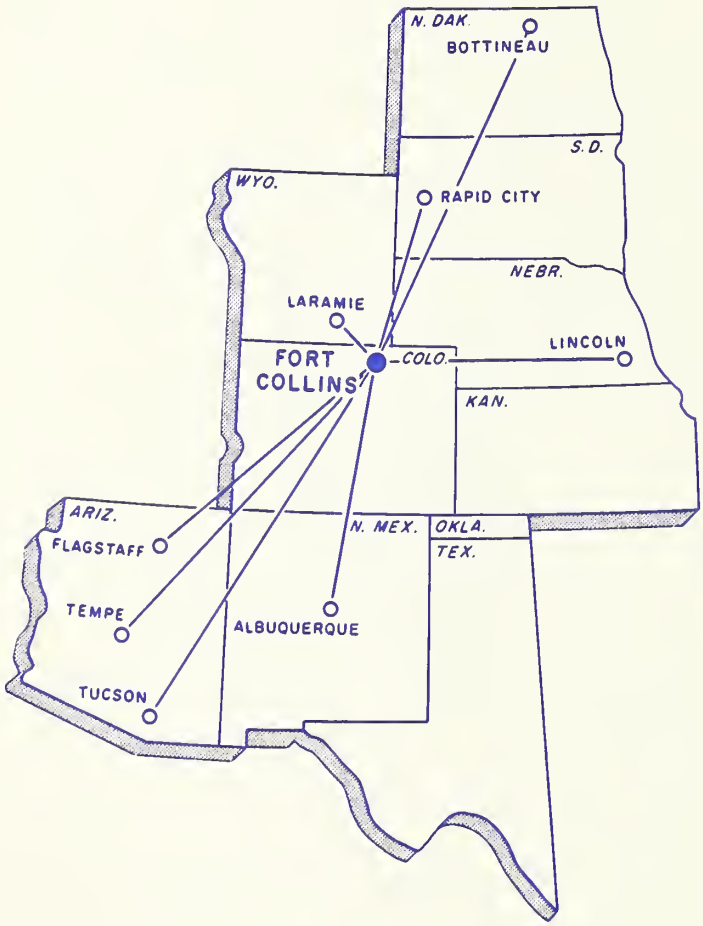
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